

**EUROPEAN PATENT APPLICATION**

Application number: 89203109.7

Int. Cl.<sup>5</sup>: **H03H 19/00**

Date of filing: 07.12.89

Priority: 22.12.88 IT 2305988

Date of publication of application:  
27.06.90 Bulletin 90/26

Designated Contracting States:  
**DE FR GB NL**

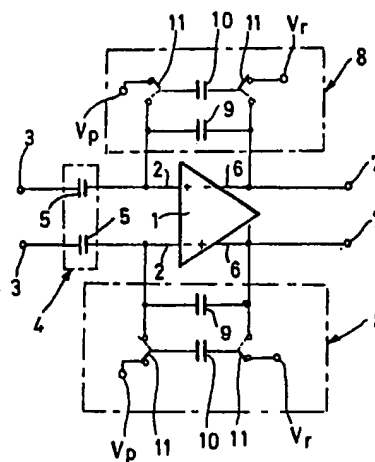
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**Completely differential filter with switched condensers using CMOS operational amplifiers with no common-mode feedback.**

The filter comprises at least one completely differential operational amplifier (1) having two inputs (2) and two outputs (6) and at least one pair of feedback circuits (8) connecting said outputs (6) with respective inputs (2) of said amplifier (1) outside of same. The operational amplifier (1) has no common-mode feedback circuit, whose functions are performed by said feedback circuits (8) external to the amplifier.



**Fig.1**

# Completely differential filter with switched condensers using CMOS operational amplifiers with no common-mode feedback

The present invention relates to a completely differential filter with switched condensers using CMOS operational amplifiers with no common-mode feedback.

The switched condenser technique (hereinafter called SC) represents the most popular analog approach for the implementation of high-precision filtering functions in commercial-type integrated circuits. The main reasons for the success of the SC technique are the following: a) resistors of large size can be replaced with very small switched condensers; b) it is possible to accomplish very accurate filtering time constants, given that they depend on capacitive ratios which are very well controlled in integrated circuits and on a clock frequency which can be generated accurately by a crystal oscillator.

Up to now this technique has been shown to be effective in accomplishing audio band filters and there is now great demand to extend it to frequencies above the audio range, up to video band frequencies, for intermediate frequency filtering devices in heterodyne and double-heterodyne systems and television products for the consumer. The maximum central frequencies (in the case of band-pass or band-stop filters) and of band-limit frequencies (in the case of low-pass or high-pass filters) obtainable in SC filters are limited by the ability of the operational amplifiers used in the above filters to attain the desired final value within half a clock period. As a consequence, high-frequency filters always require operational amplifiers with a wide unit-gain bandwidth, a high direct current open-mesh gain (for applications having a high Q value) and a good slew rate.

A second important request in the accomplishment of SC filters consists in the use of a supply voltage of 5V, so as to take advantage of technological progress and of analog/digital compatibility. Thus the dynamic field and the suppression of the power supply are also highly important design parameters.

Recently, high-frequency filters with a high Q value have been accomplished successfully by selecting very simple topologies and a completely differential structure of the operational amplifier and exploiting recent technological improvements related to short-channel processes. Completely differential operational amplifiers are preferred over their unbalanced counterparts because they determine a wider dynamic field and a greater suppression of noise due to the power supply and to the clock signal passage. The main disadvantages of the completely differential approach consist, on the

other hand, in the greater demand for area and for power due to the common-mode feedback circuit (hereinafter called CMFB) of the operational amplifier and in the limitation of the filtering rate due to the load of the CMFB circuit on the differential path.

In view of this state of the art, the object of the present invention is to accomplish a completely differential filter, suitable for implementation in an integrated circuit, which does not suffer from the drawbacks indicated above due to the common mode feedback circuit of the operational amplifier.

According to the invention such object is attained with a filter comprising at least one completely differential operational amplifier having two inputs and two outputs and at least one pair of feedback circuits of the differential signal arranged to connect said outputs with respective inputs of said amplifier outside of same, characterized in that said operational amplifier has no common-mode feedback circuit and in that the latter's function is performed by said pair of feedback circuits external to said amplifier.

In this way the drawbacks mentioned above due to the operational amplifier's CAB circuits are overcome without losing the indispensable common-mode feedback function. This allows the accomplishment of a completely differential filter having a smaller area, reduced power dissipation, greater rates of operation and a greater dynamic field.

The characteristics of the present invention shall be made evident to a greater extent by the following detailed description of its embodiments illustrated, as non-limiting examples, in the enclosed drawings, wherein:

Fig. 1 shows the overall block diagram of a completely differential filter of the first order, accomplished according to the invention;

Fig. 2 shows the circuit details of a possible CMOS operational amplifier included in the filter of Fig. 1;

Fig. 3 shows a unit consisting of a completely differential band-pass filter of the second order, accomplished according to the invention.

Fig. 1 shows a completely differential SC filter of the first order, which in a mode known in itself (say, in the US Patent No. 4,609,877 and in the European Patent Application No. 0293020 by the same Applicant) comprises an operational amplifier 1 having two inputs 2 connected to respective signal inputs 3 by means of a connecting network 4 formed by condensers 5, as well as two outputs 6 directly connected to respective signal outputs 7.

Outputs 6 of operational amplifier 1 are connected to inputs 2 of the same amplifier by means of respective negative feedback circuits 8, each of which consists of a first condenser 9 constantly connected between output 6 and input 2 and of a second condenser 10 alternatively connected between a terminal of polarization voltage  $V_p$  and a terminal of reference voltage  $V_r$  according to the position of a pair of switches 11.

With switches 11 in the position illustrated by a continuous line condensers 10 are suitably charged at a voltage  $V_p - V_r$ , while in the subsequent phase with the switches 11 in the position illustrated by a dotted line condensers 10 are connected in parallel with condensers 9.

The manner of operation of the filter of Fig. 1 and of its variations is described in the US Patent and in the European Patent Application mentioned above.

With respect to such known solutions, however, the filter according to the invention distinguishes itself in that the completely differential operational amplifier 1 does not include the usual common-mode feedback circuit.

Such function, in fact, is performed by the same negative feedback circuits 8 already normally present in the filter.

A suitable operational amplifier circuit accomplished with CMOS technology can thus be that of Fig. 2, which comprises two circuit branches 12 connected in parallel between a power supply source  $V_{dd}$  and ground and comprising, each, the series of two P-channel CMOS transistors 13 and 14 and two N-channel CMOS transistors 15 and 16. Transistors 13, 14 and 15 have their gates connected to respective polarizations  $V_{b1}$ ,  $V_{b2}$  and  $V_{b3}$ , transistors 16 have their gates connected to inputs 2 and intermediate branch points between transistors 14 and 15 are connected to outputs 6.

As an alternative to the use hypothesized in Fig. 1, an operational amplifier like that of Fig. 2 or analogous, that is, without a CMFB circuit, may be used for each of the two completely differential operational amplifiers 1, included in the second-order band-pass filter of Fig. 3.

The filter of Fig. 3, also known in itself except for the type of operational amplifier used, comprises two amplifiers 1, each with two feedback condensers 21, an input coupling circuit 22 of the capacitive type, two switched-capacity circuits 23 with MOS transistors and capacitances having polarization voltage  $V_p$  and reference voltage  $V_r$  and a multiplier circuit 24 of the capacitive type.

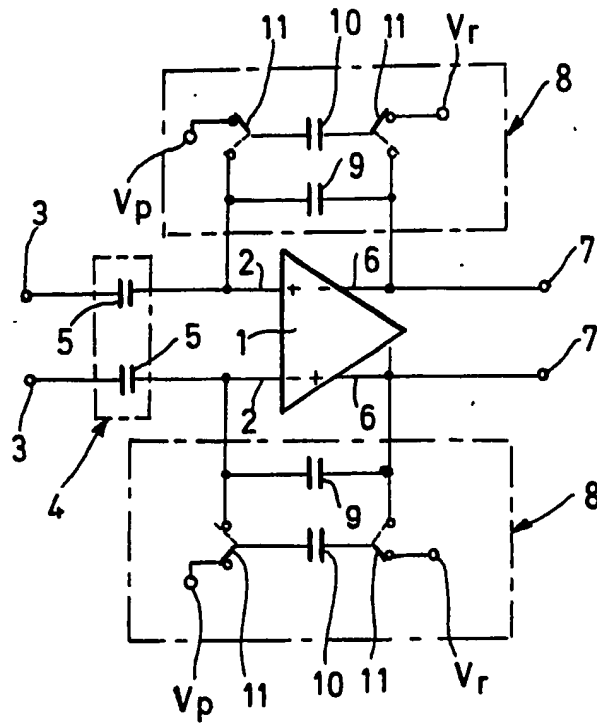
It appears evident that the two circuits 23 and one of the amplifiers 1 form the differential feedback network for the other amplifier 1, also performing for it the same function of the common-mode feedback. More precisely, the common-

mode output of each operational amplifier is forced towards the reference voltage  $V_r$ , which must be selected so as to be half the power supply voltage so as to optimize the output dynamics and must be referenced to the negative power supply so as to improve the power supply's differential suppression ratio for the same negative power supply. This is a fundamental condition for utilizing operational amplifiers such as that of fig. 2 without amplifying the noise on the negative power supply at the filter's output.

## Claims

1. Completely differential filter with switched condensers, comprising at least one completely differential operational amplifier (1) having two inputs (2) and two outputs (6) and at least one pair of feedback circuits (8) of the differential signal arranged to connect said outputs (6) with respective inputs (2) of said amplifier (1) outside of same, characterized in that said operational amplifier (1) has no common-mode feedback circuit and in that the latter's function is performed by said pair of feedback circuits (8) external to said amplifier (1).

2. Filter according to claim 1, characterized in that said operational amplifier (1) is formed by two series of CMOS transistors (13-16) connected between a voltage supply and ground and having an intermediate branch point connected to respective outputs (6) of said amplifier (1), one (16) of the transistors (13-16) of each series having its gate connected to a respective input (2) of said amplifier (1).



**Fig.1**

**Fig.2**

